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Leveraging Resistance to Change and the Skunk Works Model of Innovation*

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Abstract

We study a situation in which an R&D department promotes the introduction of an innovation that results in costly re-adjustments for a production department. In response, the production department tries to resist change by improving the existing technology. We show that firms balancing the strengths of the two departments perform better. As a negative effect, resistance to change might distort the R&D department's effort away from radical innovations. The firm can solve this problem by implementing the so-called skunk works model of innovation where the R&D department is isolated from the rest of the organization. Several implications for managing resistance to change and for the optimal design of R&D activities are derived.

JEL Codes: *L2, M12, M54, O31, O32.*

Key words: Resistance to change, innovation, skunk works model, contest.

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1 Introduction

Innovation is one of the main drivers of a firm's competitive advantage. Innovation, however, has often a disruptive effect on the organization because it is associated to or induces organizational change and adaptation (Henderson and Clark 1990). A new technology, a new product, or a new marketing method often imply the reshaping of relevant resources and expertise, the change of established norms and routines, and the rapid obsolescence of accumulated learning (Tushman and Anderson 1986). The magnitude and intensity of such effects depend on the characteristics of the innovation, with radical innovations imposing major adjustments within the organization (Henderson 1993). Change is costly, not only for the firm as a whole, but also for each of its individual members. For instance, Morrill (1991) identifies several potential sources of costs: loss of power and prestige, need to retrain and relearn, changing definition of success, fear of technology, etc. In an attempt to avoid these costs, the employees of the firm might react to change by fighting it back rather than adapting to it.

How should a firm manage this resistance to change? This issue is of central importance for a firm's innovative capability and, ultimately, survival (Gilbert 2006). To address this question, we build a model where the implementation of a successful innovation, backed by an R&D department, results in costly changes for a production department. In response, the production department tries to improve the current technology in an attempt to convince the management not to implement the innovation. As an example of the type of situation we have in mind, Foster (1986) describes the case of DuPont and its decision in the 1950s to move from the established nylon technology to the new polyester technology for the production of car tires. Behind the decision there was a conflict between production engineers at the nylon plant and researchers supporting the new technology. The production engineers managed to push the nylon technology to the limits, and provided sufficient evidence to convince the management that the nylon technology would remain competitive. The polyester technology was eventually shelved.

We model the organizational competition between the two departments using tools borrowed from contest theory. Contests are situations in which the participants expend money or effort to increase their chances of winning a prize. Examples include rent-seeking and lobbying situations, tournaments, arms races, political campaigns, athletic contests, patent races and procurement of innovations (Taylor 1997; Che and Gale 2003; Ganuza and Hauk 2006). In our model, the production and the R&D departments are involved in a contest of technologies. The R&D department tries to develop a new technology while the production department works on improving the existing one.

We show that organizations with greater resistance to change, i.e. firms whose production departments face larger costs of re-adjustment, exhibit a lower probability of introducing a new technology. However, this is not always profit reducing for the firm as a whole. Indeed, it is

shown that firms with highly motivated and productive R&D departments might benefit from a stronger resistance to change. By contrast, firms whose R&D departments are weak or badly motivated suffer from stronger resistance to change. More in general and consistent with the literature on contests, our findings suggest that firms that maintain a balance of powers between the two departments outperform firms where one department largely dominates the other.¹

Although our analysis stresses the positive effects of internal competition, we argue in the second part of the paper that (the threat of) internal competition might entail important costs for the firm. In particular, the prospect of a costly contest of technologies might push the R&D department towards low risk, incremental projects that entail low adaptation costs for the production department. Such incremental innovations meet much less internal resistance than radical innovations that require the production department to undertake more costly changes. Thus, the R&D department refrain from investigating more path-breaking research trajectories at the detriment of long-run firm profits.

We analyze an organizational solution to this problem, known as the "skunk works model" of innovation, which consists in isolating the team of researchers from the influence of the rest of the organization.² The skunk works model of innovation has received lots of attention from management scholars and has been implemented by many large technology firms, such as IBM, Siemens and Intel, but we are not aware of any formal economic model that attempts to pin down the virtues of this organizational solution. We show that adopting the skunk works model of innovation can induce the R&D department to choose a radical research trajectory in situations where an integrated R&D department would have chosen an incremental trajectory to avoid the competition with the production department.

This paper is related to several bodies of literature both in economics and management. The adoption of a new technology is a decision that has important redistributive effects within the organization. The economics literature has argued that such decisions are subject to "influence activities" by the involved parties, i.e. efforts aimed at affecting the decision maker (Meyer et al. 1992; Milgrom 1988; Milgrom and Roberts 1988). Such efforts distort resources from more productive uses, slow down the decision making process, and sometimes prevent organizational changes altogether (Schaefer 1998). Our approach can be thought of as representing a different time horizon. Shortly before the management decides which technology to use, the performances of the technologies are more or less given. The departments will therefore spend resources trying to promote their preferred technology by presenting it well, "buttering up" decision makers, etc.

¹Evidence consistent with the notion that this type of organizational competition spurs innovation can be found in Ginn and Rubinstein (1986). They study 61 new product introductions in a major chemical company. They show that product introductions leading to more intense competition, measured by how incompatible the R&D department's and the production department's goals are, tend to be more successful than product introductions causing less competition.

²A windowless facility built by Lockheed at the airport of Burbank, California, during the Cold War was known as the "skunk works". There, secret military projects were developed.

This is the situation captured by influence activity models. By contrast, we argue that there is an incentive earlier in the game to improve the technologies to have as strong a case as possible should the competition between departments take place. We focus here on this long-run effect, but this is, of course, not to say that influence activities do not exist or are irrelevant.

Organizational scholars have widely investigated the tension between the exploration of new alternatives and the exploitation of current capabilities (Levinthal and March 1993; March 1991) by employing simulation models based on routine adaptation and learning (Rivkin and Siggelkow 2003). Exploitation refers to achieving maximal profits in the current situation whereas exploration refers to the process of searching for new opportunities. In our model, the production department is involved in exploitative activities, while the R&D department explores new technological possibilities. Although we leave many of the subtleties in the background, we provide a different, incentive-based view of such a tension. Similarly to this literature, we show that firms are well-advised in trying to balance explorative and exploitative activities. However, we also find that exploitation might, under certain conditions, *increase* exploration by exposing the R&D department to tougher internal competition.

Besides the already mentioned works, our analysis is related to two papers by Rotemberg and Saloner. In Rotemberg and Saloner (1995), using a quite different model, the authors study the conflict between the sales and the production departments, with the former wanting a broad product line and the latter wanting long production lines. The firm can potentially benefit from the conflict because the two departments present valuable information concerning costs to defend their respective positions. Nevertheless, as their emphasis is on cost revelation, they do not study questions related to innovation policies, which is our main interest here. Rotemberg and Saloner (2000) analyze competition between two R&D teams inside a firm. Again, the focus of their paper is quite different from ours. Rotemberg and Saloner study how hiring a biased ("visionary") CEO can induce higher efforts by the teams, but they do not look at issues such as, e.g., the skunk works model of innovation and the tension between exploitation and exploration, which constitute the main contribution of our work.

The rest of the paper is organized as follows: The next section describes the basic model that is then solved and discussed in section 3. Section 4 contains the analysis of the skunk works model of innovation. In section 5 we analyze and discuss several important contractual assumptions, and thus extend our basic framework. Section 6 concludes with some implications for managers. All technical proofs are in the appendix.

2 The Basic Model

Our firm is composed by three risk-neutral agents: A production unit (PU), a research unit (RU) and a management unit (MU), which we describe in more detail below. The firm is actually employing a standard technology to produce a given product, which results in a profit of $\pi_1 = 0$ if no further improvements are made.

The Research Unit The RU expends unobservable *creative effort*, e_R , that probabilistically generates valuable innovations or "ideas". The creative effort results in a new technology of value Δ_R with probability p where $\Delta_R = \gamma e_R$, and $\gamma > 0$. With the complementary probability, $1 - p$, the effort is fruitless. The cost of effort is $c(e_R) = e_R$. The RU receives a reward B if the new technology is adopted and 0 if it is not. Here, B can contain both monetary (paid by the firm) and non-monetary elements such as peer-recognition, career concerns or personal satisfaction. We will discuss both these possibilities below. The RU is wealth and credit constrained, and a possible monetary bonus must therefore be non-negative. The RU maximizes its utility, which is given by the difference between the expected reward and the cost of creative effort.

The Production Unit The PU expends two types of effort: *Production effort* and unobservable *defensive effort*. The production effort is indispensable for running the technology. The PU receives a payoff normalized to zero as compensation for the production effort. The defensive effort, e_P , enhances the performance of the existing technology. We have in mind changes in the layout of production facilities, re-engineering of processes, cost reductions obtained through marginal innovations, elimination of inefficiencies, changes in the design of the products which bring about cost savings or quality improvements, and so on. The defensive effort increases the payoff of the existing technology by $\Delta_P = e_P$. The total value of the existing technology is therefore Δ_P . Such effort does not come for free, and the PU incurs a cost of $c(e_P) = e_P$. We call the effort "defensive" because the PU expends it only when threatened by a new technology. The reason is that the PU has made technology-specific investments in the existing technology such as mastering it, learning how to deal with break downs, establishing routines and rules, etc. A change of technology forces the PU to reinvest in order to be able to produce. The firm can partially compensate such costs through training programs, monetary incentives and other policies. However, totally offsetting the inconveniences of change might be hard.³ In particular, we assume that the introduction of a new technology imposes a cost of F on the PU. Faced with the potential threat of a new technology developed by the RU, the PU is thus willing to exert effort to improve the existing technology, thereby reducing the likelihood that the new technology is adopted. Put differently, the PU tries to resist change. As an alternative to resisting

³As we discussed in the introduction, the cost of change for the PU should be interpreted broadly to include also psychological factors.

change, the PU can leave the firm. We assume that this option bears a cost of $K > 0$. K can be interpreted as relocation costs, search costs, reputation concerns, risk of being unemployed or simply quasi-rents that are lost if the PU moves to another firm. We start by considering non-monetary incentives only (Section 3) but introduce monetary incentives later on (Section 5). All wages to the PU must be non-negative due to wealth and credit constraints. The PU maximizes its expected utility, which is equivalent to maximizing the total reward if the current technology is kept, i.e. the avoided cost of change plus a possible monetary bonus, minus the cost of the defensive effort (provided that this is a better option than leaving the firm).

The Management Unit The last building block of our firm is the MU whose aim is to maximize firm profits. We assume that the firm is able to implement at most one technology, either the existing technology or the new one. There are several reasons why this might be the case. First, the two technologies might produce exactly the same product. Using both would therefore lead to inefficient duplication of costs. Second, the two technologies might depend on different organizational routines, and nurturing both of them would generate incompatibilities. Finally, the technologies might compete for the use of scarce, complementary resources such as managerial talents, dedicated sales forces, financial resources, etc. (Cassiman and Ueda 2006). The key decision of the MU is therefore the choice of the technology. The MU either decides to continue with the existing technology or to implement the new technology, in which case the PU has to adapt to the new course of actions. Another important choice of the MU concerns the contracts offered to the two units. The profits of the firm consist of the payoffs from the technology chosen minus all potential payments as compensation or monetary rewards.

Timing If feasible, the MU chooses the reward structure. Then, the RU expends creative effort to generate a new technology. Simultaneously, the PU expends defensive effort to improve the performance of the existing technology. After uncertainty is resolved, the MU takes a decision about which technology to use. At the end of the game, payoffs are realized.

3 Solution of the Basic Model

To grasp the intuition and understand the key properties of our framework, we solve the model in its simplest version. The robustness of the key properties is discussed later on. We assume here that the MU cannot use monetary instruments to reward our units. Then, the reward to the PU for maintaining the current technology is the adjustment cost, F , that it has to bear if the new technology is introduced. The reward, B , to the RU captures non-monetary benefits from having its innovation implemented. What we have in mind here are benefits such as personal satisfaction, career concerns, internal recognition and status that motivate the RU but do not

represent an expense for the firm.⁴ We will also assume that $K \geq pF$, which implies that the PU will never use the option to leave the firm.

We solve the game starting from the last stage in which the MU makes a decision about the technologies. Suppose that the RU has developed a new technology. The MU will reject the technology proposed by the RU if $e_P > \gamma e_R$, whereas it will abandon the existing technology if $e_P < \gamma e_R$. This selection rule for the technology is extremely simple and only requires the MU to make ordinal comparisons among alternatives.⁵ Both the RU and the PU exert efforts in order to influence the MU's decision in their respective interest. This competition between departments can be conceived as a contest with exogenously given different prizes for the contestants. As tie-breaking rule, we assume that if $e_P = \gamma e_R$ the MU chooses the technology of the dominant unit, i.e. the unit with the highest willingness to invest in the contest. This assumption is commonly made in the contest literature (see, for instance, Che and Gale 2003, page 653). It is of a similar nature to the assumption that guarantees the existence of a pure strategy equilibrium in a game of Bertrand competition with homogenous products and asymmetric costs.

We distinguish two cases: $F > \gamma B$ and $F < \gamma B$. In the first case the PU would win if both units invested the full value of their prize into the contest. We will say that the PU "dominates" in this case. It corresponds, e.g., to the situation where inertial forces inside the firm are very strong and production workers and engineers are very adverse to change (F large), i.e. there is a strong resistance to change. The researchers are not or cannot be strongly motivated (B low), or their creative effort maps very poorly into valuable technology (γ low). In the second case the RU dominates, i.e. it would win if both units invested the full value of their prize into the contest. This corresponds to a firm with very flexible human capital in its production department that does not fear change (F low). It is also a firm with highly motivated and capable researchers (B high and γ high).

Before finding the equilibrium of the contest, we establish the following result.

Lemma 1 *There is no equilibrium in pure strategies.*

Intuitive proof: Since the new technology only materializes with probability p , the maximum amount of effort that the PU and the RU are willing to exert are pF and pB , respectively. Consider the case in which $F > \gamma B$. The other case is symmetric. For any $e_R \leq pB$, the PU is willing to make a defensive effort such that the MU's decision is tilted in its favor. If it chooses such an effort, the best response of the RU is to exert no creative effort. However, the best response to $e_R = 0$ is $e_P = 0$ given the tie-breaking rule assumed. This is still not an equilibrium

⁴A recent paper by Stern (2004) shows that scientists are willing to give up some monetary rewards in exchange for the possibility to work on their preferred research agenda.

⁵In addition, different selection rules based on cardinal comparisons among alternatives suffer from commitment problems since, although possibly profit enhancing ex-ante, they imply inefficient decisions ex-post. We discuss this issue further in the conclusion.

because the RU can do better by exerting a creative effort just large enough to win the contest. As this circular argument suggests, no equilibrium in pure strategies exists. ■

Lemma 1 is a standard result in the contest literature (Taylor 1997; Che and Gale 2003). A potential avenue to rescue a pure strategy equilibrium is to make the relationship between the efforts of the contestants and the value of their technology less deterministic.⁶ For instance, one could assume that Δ_R and Δ_P are stochastic variables whose distributions depend on e_R and e_P respectively, and that the effort cost functions are convex. Although this formulation would deliver a pure strategy equilibrium, it turns out to be much harder to handle analytically. Thus, the literature on contests has broadly resorted to mixed strategy equilibria that are much easier to solve in explicit form (Che and Gale 2003; Burguet and Che 2004; Konrad 2006). Since the solution allows a very intuitive interpretation as well, we have chosen to follow in this tradition.

Lemma 2 states the mixed strategy equilibrium for the case where the RU dominates the contest, $F < \gamma B$. In the proof (see the Appendix) we derive the equilibrium in some detail to illustrate how it is constructed. Hillman and Riley (1989) show that the equilibrium reported here is in fact the unique equilibrium.

Lemma 2 ($F < \gamma B$: The RU dominates) *In equilibrium the PU randomizes according to the distribution function $G(e_P) = 1 - \frac{F}{\gamma B} + \frac{e_P}{p\gamma B}$ for all $e_P \in [0, pF]$ and the RU randomizes according to the distribution function $H(e_R) = \frac{\gamma e_R}{pF}$ for all $e_R \in [0, \frac{pF}{\gamma}]$. The expected payoffs for the PU, the RU and the firm are respectively: $U_P = -pF$, $U_R = p\left(B - \frac{F}{\gamma}\right)$, and $\Pi = \frac{pF}{\gamma B} \frac{F(3-2p)+3\gamma pB}{6}$.*

The next lemma summarizes the equilibrium outcome for the case where the PU dominates, $F > \gamma B$. The equilibria of all the contests we present in the rest of paper are derived using the method illustrated in the proof of Lemma 2. For this reason, we present the equilibrium strategies, often in the Appendix, but leave out the algebra. Details are available from the authors upon request.

Lemma 3 ($F > \gamma B$: The PU dominates) *In equilibrium the PU randomizes according to $G(e_P) = \frac{e_P}{p\gamma B}$ for all $e_P \in [0, p\gamma B]$ and the RU randomizes according to $H(e_R) = 1 - \frac{\gamma B}{F} + \frac{\gamma e_R}{pF}$ for all $e_R \in [0, pB]$. The expected payoffs for the PU, the RU, and the firm are respectively: $U_P = -p\gamma B$, $U_R = 0$, and $\Pi = \frac{B}{F} \frac{\gamma p(3F+\gamma pB)}{6}$.*

The following remarks describe and compare the equilibrium outcomes for different values of the exogenous parameters.

⁶Another alternative is to use a contest function to determine the winner. Here, the probability to win the prize increases with a contestant's effort and decreases with the rival's effort in a continuous manner. We have preferred not to resort to such a function because it leaves unspecified the decision process, which plays an important role in our story, and it requires further assumptions on how efforts map into profits.

Remark 1 (*Expected efforts*) The expected creative effort is $\frac{B^2 p \gamma}{2F}$ if $F > \gamma B$ and $\frac{F p}{2\gamma}$ if $F < \gamma B$, whereas the expected defensive effort is $\frac{B p \gamma}{2}$ if $F > \gamma B$ and $\frac{F^2 p}{2B\gamma}$ if $F < \gamma B$.

Remark 2 (*Comparative statics*) When the RU dominates, the expected creative effort is increasing in F and decreasing in γ , whereas the expected defensive effort is increasing in F and decreasing in γ and B . Expected profits are increasing in F and decreasing in γ and B . When the PU dominates, the expected creative effort is increasing in B and γ and decreasing in F , whereas the expected defensive effort is increasing in B and γ . Expected profits are increasing in B and γ and decreasing in F . Finally, expected efforts as well as expected profits are always increasing in the probability that the new technology is developed, p .

To interpret these comparative static results one should bear in mind that the efforts exerted by the two units are aimed at influencing the MU's decision between the existing and the new technology. First, it is obvious that the efforts of the PU and the RU are (weakly) increasing in their respective rewards, F and B . Second, it is interesting to notice that a larger F does not necessarily mean less profits, as one might have expected given that F parametrizes resistance to change.⁷ In fact, when the RU dominates, a larger F implies that both units exert more effort and hence profits are higher.⁸ More in general, these comparative statics suggest that the firm always prefers to maintain a balance of powers between the RU and the PU. In particular, for given B and γ the profits of the firm are maximized for the value of F that makes the contestants equally strong, $F = \gamma B$. These arguments are summarized in the following proposition.

Proposition 1 (Principle of balanced competition) *The firm benefits if the relative strength of the two departments is balanced.*

The principle of balanced competition is perhaps best understood using an analogy to a track race. A weak runner will not spend a lot of energy racing against a much faster competitor as the chance of winning the race is low. The slow pace of the weak runner, in turn, slows down the strong runner. After all, there is no reason to waste energy and risk injury by running fast when this is not needed to win the race. In order to make runners perform their best, they should thus be matched against a competitor of equal strength. This is the same basic idea underlying the result of Proposition 1.

A couple of issues related to this principle deserves discussion. We study competition in technologies, but Proposition 1 applies more broadly to competitions inside the firm. Inderst and Laux (2005), e.g., analyze how competition for scarce internal funds can stimulate innovation.

⁷By the same argument, having a more motivated R&D department might not always be profit enhancing.

⁸Notice that the probability of the RU winning the contest is $pB\gamma/2F$ when PU dominates and $p(1 - F/2B\gamma)$ otherwise. Thus, the expected probability of observing a change in the technology is still decreasing in F .

They find, in the line with Proposition 1, that the positive effect of competition on innovation is strongest when the departments are equally strong.

Until now we have focused solely on the positive effects of internal competition. Obviously, competition between two departments might have several negative aspects that we do not account for in our framework. For example, the development of a new technology might require a strict collaboration between production and R&D where both departments benefit from reciprocal feedback. Strong competition might hamper such collaboration. Strong internal competition might also generate undesirable behaviors from each department, like for instance unproductive influence activities (Milgrom and Roberts 1988). Firms might have to optimally design their organizations to minimize such negative side effects and fully exploit the benefits of internal competition.⁹ In section 4, we shall analyze a situation in which too tough internal competition leads to a distortion in the RU's choice of the research trajectory, and we study how this problem can be ameliorated with an appropriate organizational design.

3.1 Exploitation versus Exploration

The principle of balanced competition is reminiscent of the suggestion by organization theorists that the firm should pursue a balance between exploration of new alternatives and the exploitation of current capabilities (Levinthal and March 1993; March 1991; Rivkin and Siggelkow 2003). As Levinthal and March (1993) put it, "...the basic problem confronting an organization is to engage in sufficient exploitation to ensure its current viability and, at the same time, to devote enough energy to exploration to ensure its future viability".

However, exploitation and exploration are in constant tension. In fact, adaptation to existing environmental demands may foster structural inertia and reduce a firm's capacity to adapt to future environmental changes and new opportunities. In other words, a firm that invests in augmenting its current capabilities and maintaining its current focus might perform rather poorly in generating ideas that are outside its core capabilities. Our framework can also handle this possibility, and provide a different, incentive-based explanation of the well-researched tension between exploitative and explorative activities.

Assume that there is a previous period ($t = 0$) before the very same game described above ($t = 1$). In period 0 the firm uses the standard technology. This activity generates profits $\pi_0(\alpha)$ where α measures the degree of exploitation. By exploiting the current technology, the MU takes actions that make the production and distribution more efficient, eliminate slacks, routinize activities, enhance specialization and expertise. Hence, we assume that $\partial\pi_0(\alpha)/\partial\alpha > 0$. The cost of pushing up the exploitation of the standard technology in period 0 is $C(\alpha)$. Here, $C(\alpha)$ is assumed to be sufficiently convex to ensure that the firm's problem is concave in α .

⁹Milgrom (1988) has, e.g., argued that bureaucratic rules limiting managerial discretion can be used to reduce wasteful influence activities.

In period 1 the PU can improve the standard technology as before. Thus, the improvements are on top of $\pi_0(\alpha)$. The more the firm invests in the standard technology in period 0 the stronger the PU is in period 1. For simplicity, we assume that $p = 1$. Also, let $\gamma B - \pi_0(\alpha) > 0$ in the relevant range, otherwise the best strategy for the RU is always to exert zero creative effort.

The following lemma reports the expected period 1 profits as a function of α and $\pi_0(\alpha)$.

Lemma 4 *If the PU dominates ($F + \pi_0(\alpha) > \gamma B$), then*

$$\pi_1(\alpha) = \frac{(B\gamma - \pi_0(\alpha))(B\gamma(3F + B\gamma) + (3F - 2B\gamma)\pi_0(\alpha) + \pi_0(\alpha)^2)}{6BF\gamma}$$

and $\partial\pi_1(\alpha)/\partial\alpha < 0$. If instead the RU dominates ($F + \pi_0(\alpha) < \gamma B$), then

$$\pi_1(\alpha) = \frac{F^2 + 3BF\gamma - 3F\pi_0(\alpha) + 12B\gamma\pi_0(\alpha)}{6B\gamma},$$

and $\partial\pi_1(\alpha)/\partial\alpha > 0$.

We now turn to the firm's optimal choice of α in period 0.

Proposition 2 *Let a myopic firm be a firm that maximizes profits period by period. If a myopic firm in period 0 chooses a level of α such that the PU dominates in period 1, then a fully rational, forward-looking firm invests less in the standard technology than a myopic one. However, if a myopic firm in period 0 chooses a level of α such that the RU dominates in period 1, then a fully rational, forward-looking firm invests more in the standard technology than a myopic one.*

Greater investment in exploiting the standard technology makes the PU stronger. Indeed, it becomes harder for the RU to produce enough creative effort to change the status-quo. Put differently, greater exploitation tilts the contest between the RU and the PU in favor of the latter. As long as the PU is already strong and has an advantage in the contest, exploitation makes the competition between the two units even more unbalanced, so it erodes incentives to exert efforts and reduces profits in period 1. For this reason, a forward-looking firm would invest less in the standard technology than a myopic firm that only considers period 0 profits when choosing the optimal degree of exploitation. This corresponds well to the notion that exploiting the current technology may hinder the exploration of future opportunities. Nevertheless, our model suggests that this is only a part of the story. When the RU is the strongest unit, for instance because the firm is operating in a fast developing technological area, further exploitation helps making the competition between the two units tougher and increases both explorative activities and expected profits.

4 The Skunk Works Model of Innovation

The outcome of the innovation process not only depends on the intensity of the creative effort, but also on the locus of search. Often researchers have the freedom to choose among an array of research trajectories that encompass different levels of uncertainty, different types of potential innovations, different knowledge bases, different technological competences, among other features. Most importantly from our perspective, while some of these research trajectories, if successful, might lead to important adaptation costs for the PU (large F), others might instead come at small or no adaptation costs ($F \simeq 0$). Indeed, some research trajectories are more probable to deliver "radical innovations", while other trajectories are more likely to lead to "incremental innovations". Radical innovations are based on a new set of routines and expertise. Incremental innovations are based on existing routines and expertise (Henderson 1993).¹⁰

Not surprisingly, a research trajectory which might lead to radical innovations (henceforth, a radical trajectory) is likely to meet stronger resistance from the PU (Ginn and Rubenstein 1986). Indeed, Gilbert (2006) argues that the organizational rigidity increases in the level of threat perceived by the organization. To avoid a costly internal contest, the RU might thus turn to a research trajectory that produces incremental innovations (henceforth, an incremental trajectory). Hence, although the competition between the PU and the RU acts as an incentive mechanism, it might also produce a distortion towards less profitable, incremental trajectories.

To stimulate radical innovations, researchers are often isolated from the influence of the rest of the organization. This has become known as the "skunk works model" of innovation. The skunk works model was, e.g., the organizational design followed by IBM to nurture the by then revolutionary PC (Roberts 2004), and it is employed by many large innovative firms, such as Intel, HP and Apple, to develop potential breakthroughs.

The skunk works model is claimed to bring several advantages. Echoing the discussion on myopia in organizational learning (March 1991; Levinthal and March 1993), it gives researchers the necessary autonomy, independence and freedom to escape the established lines of thought and produce novel ideas. See, also, Christensen (1997). Closer to the argument of this paper, it can also help to overcome the resistance that radical innovations meet inside the organization.¹¹ In the following, we explore the latter advantage using a variation of the basic model developed in sections 2 and 3.

¹⁰In the organization literature these two kinds of innovations are often referred to as competence destroying and competence enhancing innovations (Tushman and Anderson 1986).

¹¹The Aurora project set up by Teradyne in the mid 90s is exemplar of this situation. Teradyne was the market leader (with about 22% of the world market) in automatic test equipment used in the production of semiconductors. Teradyne employed a technology based on UNIX operating system software, and was trying to shift to the CMOS technology based on Windows NT. In order to overcome the very high organizational resistance to this change, the company decided to create an independent unit, called the Aurora project, that had the autonomy and resources to work on the new technology (Bower 2005).

4.1 The Model

Let us assume that there are two possible research trajectories, an incremental trajectory and a radical trajectory. The RU chooses the research trajectory before the game analyzed in section 3 starts.

Assumption 1. *The characteristics of the two trajectories are:*

Incremental trajectory: $F_I \geq 0, p_I = 1, \gamma_I = 1, B_I = B > 0$,

Radical trajectory: $F_R > F_I, p_R = p < 1, \gamma_R = \gamma > 1, B_R = \rho B$ with $\rho > 1$.

Assumption 2. *The RU dominates when the incremental trajectory is chosen, i.e. $B > F_I$.*

Assumption 1 makes operational the idea of different research trajectories. The incremental trajectory leads to innovation with certainty. The innovation builds on the current competences and expertise, so it results in smaller adaptation costs for the PU. Nevertheless, for the RU it is not a particularly "exciting" trajectory, and the reward from having the new technology implemented is lower. Instead the radical trajectory is riskier, imposes larger adaptation costs upon the PU, but implies a higher potential reward for the RU. Assumption 2 and Lemma 2 imply that the RU is guaranteed a positive expected payoff if it chooses the incremental trajectory in equilibrium, i.e. $U_R = B - F_I > 0$. This is more than plausible as the resistance exerted by the PU is low. In the limit for $F_I = 0$, Assumption 2 is always satisfied.

Finally, to make the problem interesting, we assume that if the PU observes the choice of the trajectory and can react to it, the RU chooses the incremental trajectory rather than the radical one to avoid a costly internal contest with the PU. The cost of internal competition is thus sufficiently high to potentially influence the choice of the research trajectory. From Lemmata 2 and 3 it follows that this is the case if the following condition holds:

Assumption 3. $B - F_I > \text{Max} \left\{ 0, p(\rho B - \frac{F_R}{\gamma}) \right\}$.

Below we shall investigate whether the firm can improve its expected profits by isolating the RU and creating a skunk works model of innovation. The crucial difference between having the RU integrated in the firm and the skunk works model is the amount of information that the PU receives about the RU's actions. In particular, we assume that the PU observes the choice of the research trajectory if the RU is integrated in the firm but it does not if it is isolated. From a game theoretic point of view the difference between an integrated innovation model and a skunk works model boils down to the timing of the game. In the integrated model, analyzed so far, the research trajectory is chosen (and observed) before defensive and creative efforts are exerted. In

the skunk works model the choices of research trajectory and efforts are all simultaneous.¹² For simplicity, we focus on pure strategies in the choice of the research trajectory.

The timing of the game is as follows. At $t=1$ the MU decides how to organize innovation activity by choosing between an integrated model and the skunk works model. At $t=2$ the RU chooses which research trajectory to focus on, radical or incremental. At $t=3$ the two units simultaneously exert effort. Then, in case of the radical trajectory, nature determines whether the new technology is a success or a failure. At $t=4$ the MU observes the outcome of the innovation process and decides whether to adopt the new technology. Finally, at $t=5$ all payoffs are realized.

4.2 The Equilibrium Analysis

The next proposition states our main result concerning the skunk works model.

Proposition 3 *Let $pp > 1$, i.e. the expected reward of the RU is larger in case of radical trajectory. Then, the RU chooses the radical trajectory under the skunk works model of innovation and the incremental trajectory under the integrated model of innovation.*

Proposition 3 shows that by implementing a skunk works model the firm can make the radical trajectory the equilibrium outcome of the game when this trajectory is sufficiently attractive for the RU. By contrast, assumption 2 implies that this is never the equilibrium outcome under the integrated innovation model. The intuition behind this finding is the following: In the integrated innovation model, the PU observes the choice of the trajectory. The radical trajectory is therefore unattractive for the RU because it results in strong defensive effort from the PU. In the skunk works model, on the other hand, the PU does not observe the trajectory chosen. Hence, if the radical trajectory is sufficiently attractive for the RU, the choice of the incremental trajectory cannot be sustained as an equilibrium outcome. The RU would deviate to the radical trajectory in such an equilibrium because it could do so without triggering additional defensive effort by the non-suspecting PU. We show in the proof of Proposition 3 that the skunk works model instead results in an equilibrium where the RU chooses the radical trajectory. Of course, this is expected by the PU, and the two units exert therefore high effort in equilibrium.

Loosely speaking, in the integrated model the PU and RU can "collude" on the incremental trajectory, an outcome they both prefer vis-à-vis an equilibrium where the radical trajectory is chosen because the PU punishes a deviation to the radical trajectory by exerting a high amount of defensive effort. Instead, in the skunk works model of innovation the collusion cannot be sustained because the PU does not observe such a deviation.

¹²The research trajectory is chosen before the creative effort, but these two choices are observed simultaneously by the PU.

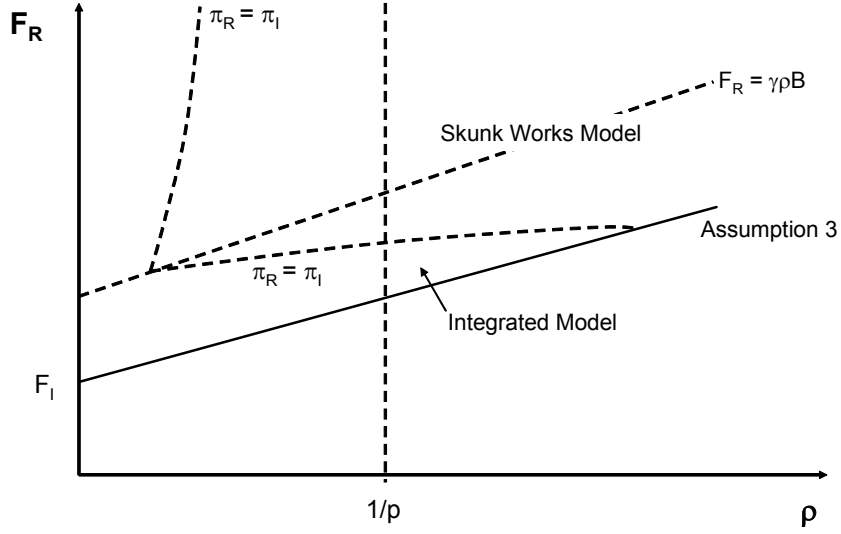


Figure 1: The equilibrium choice of the innovation model in a specific example ($B = 0.5$, $p = 0.5$, $F_I = 0.4$, $\gamma = 1.2$). Assumption 3 is satisfied above the line with this legend. When the radical trajectory is chosen the PU dominates above the $F_R = \gamma\rho B$ -line and the RU dominates below. The skunk works model changes the equilibrium outcome from the incremental to the radical trajectory to the right of the line $\rho = 1/p$. The radical trajectory results in higher profits than the incremental trajectory north-east of the two $\pi_R = \pi_I$ -lines.

Although the skunk works model can induce the RU to choose a radical trajectory under circumstances in which it otherwise would have chosen an incremental trajectory, it depends on the specific parameters of the two trajectories whether or not this is beneficial to the firm. Notice that when $F_I = 0$ the incremental trajectory gives rise to expected profits equal to zero, thus the firm always prefers the radical trajectory. In general, however, it is necessary to compare the expected profits of the two trajectories using Lemmata 2 and 3.¹³

Figure 1 illustrates the equilibrium choice of the innovation model for a numerical example. The interesting part of the figure is to the right of the $\rho = 1/p$ -line where the skunk works model induces the RU to switch to the radical trajectory (Proposition 3). In this region the MU implements the skunk works model for high values of F_R and ρ . Here, the stakes are high for the two units when the radical trajectory is chosen, which, in turn, translates into high efforts and profits. For lower values of F_R and ρ , the incremental trajectory is more profitable, and the MU keeps the RU integrated in the firm.

¹³Of course, the skunk works model can have several costs that we have ignored in the present formulation for the sake of simplicity. For instance, the skunk works model can increase managing costs, can reduce collaboration between the PU and the RU, or can simply have important set up costs. All these elements should be taken into account and would reduce its profitability.

Summarizing, our analysis imply that the firm can benefit from a skunk works model when resistance to change in case of a radical innovation is particularly strong, and would induce researchers to follow more incremental research trajectories under the integrated model. This problem is particularly acute in organizations that show very high adaptation costs in case of radical innovations. This is often the case for large bureaucratic corporations or established market leaders within a given technological paradigm (Tushman and Anderson 1986; Ghemawat 1991; Henderson 1993).

5 Monetary Incentives

In this section we generalize the previous analysis by introducing monetary incentives and participation constraints for the PU and the RU. To simplify the analysis, we assume that the RU faces monetary incentives only, whereas the PU is motivated by a combination of monetary incentives and the cost of change, F .

The use of monetary incentive schemes provides the MU with better tools to shape the incentives inside the organization. At the same time, the participation constraints force the MU to partly internalize the costs that internal competition imposes on the PU and the RU.

We start by analyzing the optimal incentive scheme in a benchmark case where it is possible to contract directly on the value of the technologies. Afterwards, we turn to the analysis of the main case where contracting possibilities are more limited and internal competition plays an important role in providing incentives.

5.1 Benchmark Case: Contracting on Value

5.1.1 The Setup

The MU offers a contract \mathcal{C}_P to the PU that specifies the wage W as a function of the value of the current technology V_P , i.e. $\mathcal{C}_P = W(V_P)$. Similarly, the RU is offered a contract \mathcal{C}_R that specifies the wage B as function of the value of the new technology, V_R . The contract also specifies a wage $B(\emptyset)$ if the RU reports that no innovation is made; thus, $\mathcal{C}_R = (B(V_R), B(\emptyset))$. Due to wealth and credit constraints, all wages must be non-negative.

5.1.2 The Optimal Contracts

The contracts have to induce the desired efforts and thereby offer a payoff that is no less than the outside option. In this setup it is particularly simple for the MU to control the two units' efforts because there is a one-to-one relation between the effort and the value of the technology. The MU can thus offer a contract that pays a strictly positive wage if and only if the technology has a value corresponding to the desired effort level.

The following proposition states the optimal contracts.

Proposition 4 *Suppose that it is possible to contract on the value of the technologies. Then, the optimal contracts induce the maximal creative effort and no defensive effort:*

$$\begin{aligned} \mathcal{C}_P : W(V_P) &= \begin{cases} \text{Max}\{0, pF - K\} & \text{if } V_P = 0, \\ 0 & \text{otherwise.} \end{cases} , \\ \mathcal{C}_R : B(V_R) &= \begin{cases} \bar{e}_R/p & \text{if } V_R = \gamma\bar{e}_R, \\ 0 & \text{otherwise.} \end{cases} \quad \text{and } B(\emptyset) = 0. \end{aligned}$$

Proposition 4 shows that if contracting possibilities are very good, the MU will rely solely on the effort of the RU. The reason is two-fold. First, the RU is induced to exert the highest effort because creative effort is more productive than defensive effort. The investment of one unit of creative effort produces a new technology with an expected value of $p\rho > 1$ whereas one unit of defensive effort only improves the value of the current technology by 1. Second, given the PU's technology is implemented only if the RU is unsuccessful, which occurs with probability $1 - p$, the defensive effort has a negative net value. The participation constraint of the PU forces the MU to internalize both the costs and the benefits of defensive effort, and thus the PU is not induced to exert defensive effort.

The contract \mathcal{C}_R compensates the RU for the cost of effort and leaves the RU with an expected payoff of zero. The contract \mathcal{C}_P ensures the participation of the PU by paying a positive fixed wage if the expected cost of implementing the new technology is higher than the cost of switching employer.

More generally, the analysis of the benchmark case highlights the two distinct roles that defensive effort plays in the basic model. It spurs creative effort by intensifying the internal competition in technologies, and it increases profits directly in situations where the RU is unsuccessful or develops a new technology of lower value than the current technology. If the MU can control the creative effort by contracting on the value of the new technology, the former role of defensive effort disappears. The latter role still remains, but this alone does not justify the cost of monetary incentives.

5.2 Contracting on the Implementation of the Technology

We now assume that it is either impossible or prohibitively expensive for outsiders to measure the value generated by the technology. This is, e.g., likely to be the case in large diversified firms with many different sources of revenues where it is difficult to verify the exact project cash flow in court. Thus, contracts based on the value of the technology are no longer feasible. Alternatively, the MU could contract on certain characteristics of the technology such as design and functionality, but we assume that it does not possess the necessary technical expertise to procure technologies in this way. We follow Rotemberg and Saloner (1994, 2000) in assuming

that the only information available to contract upon is whether the technology proposed by the RU is implemented or not. This can either be thought of as an explicit contract upheld in court or as an implicit contract maintained through reputational concerns.

5.2.1 The Setup

At the beginning of the game the MU offers a contract to each of the two units. The contract to the RU consists of a bonus B if the new technology is implemented, $\mathcal{C}_R = B$. The contract to the PU consists of a bonus W if the current technology is maintained. The net utility resulting from the bonus is not always sufficient to compensate for the cost of change. For this reason, the contract to the PU might also include a fixed wage \widetilde{W} to ensure participation of the PU, $\mathcal{C}_P = (W, \widetilde{W})$.

The two units observe the offers made and calculate the expected payoff from accepting the contract. They accept the contract if and only if the expected payoff is greater than the outside option. If the contracts are accepted, the RU and the PU simultaneously exert efforts. After uncertainty is resolved, the MU chooses the most profitable technology. At the end of the game, wages are paid and profits are realized.

5.2.2 The Optimal Contracts

We solve the game backwards and look first at the MU's choice between the two technologies. Unlike the basic model, the MU takes the bonuses into account because they represent a cost of using the technology in question. The MU chooses the new technology developed by the RU if $V_P - W \leq V_R - B \Leftrightarrow e_P - W < \gamma e_R - B$. Hence, the PU dominates the RU in the contest of technologies if and only if $p(F + W) - W \geq p\gamma B - B$.

From the analysis of the basic model, it should be clear that the MU would never offer bonuses such that the RU dominates the internal competition. If so, the MU could reduce B by some small amount, which would both reduce the expected wage bill and increase the expected efforts due to tougher internal competition. We can thus restrict attention to contracts such that the PU weakly dominates the competition.

The following lemma summarizes the analysis of the competition between the PU and the RU:

Lemma 5 *Suppose that the PU and the RU have accepted the proposed contracts. Let $pF - (1 - p)W \geq (p\gamma - 1)B$ such that the PU dominates the internal competition. The expected payoffs for the PU, the RU, and the firm are, respectively: $U_P = \widetilde{W} - (\gamma - 1)B$, $U_R = 0$, and*

$$\Pi(B, W, \widetilde{W}) = \begin{cases} \frac{(B-W)^2(2B+3F+W) - 3Bp\gamma(B^2+2BF+W^2) + 3(Bp\gamma)^2(F+W) + (Bp\gamma)^3}{6Bp(F+W)\gamma} - \widetilde{W} & \text{if } B > W \\ \frac{B((3p\gamma-6)(F+W) + Bp^2\gamma^2)}{6(F+W)} - \widetilde{W} & \text{otherwise} \end{cases}.$$

At the first stage of the game, the MU decides which contracts to offer. The MU does not have to worry about the RU rejecting the contract, as the RU can secure itself a payoff of zero by choosing $e_R = 0$. The PU can avoid the cost of effort by choosing $e_P = 0$ but not the cost of change. Hence, the contract \mathcal{C}_P has to satisfy a voluntary participation constraint (VPC_{PU}) that ensures to the PU an expected payoff greater than or equal to the outside option.

Using the results of Lemma 5, the optimal contracts solve the following program:

$$\begin{aligned} \text{Max}_{\{B, W, \widetilde{W}\}} \Pi(B, W, \widetilde{W}) & \quad (\text{Program of the MU}) \\ \text{st. } \widetilde{W} - (p\gamma - 1)B & \geq -K & \quad (VPC_{PU}) \end{aligned}$$

The next proposition characterizes the solution to this program.

Proposition 5 *Suppose that it is possible to contract upon the implementation of the new technology. Then, the optimal contract to the PU neither includes a fixed wage nor a bonus if the current technology is maintained: $\mathcal{C}_P = (W, \widetilde{W}) = (0, 0)$. The optimal contract to the RU is as follows:*

- i) If $pF \leq K$, the optimal contract is chosen such that the competition is balanced: $\mathcal{C}_R = B = pF/(p\gamma - 1)$.*
- ii) If $pF > K$, the optimal bonus is chosen such that the participation constraint of the PU binds: $\mathcal{C}_R = B = K/(p\gamma - 1)$.*

Proposition 5 confirms the principle of balanced competition but with some qualifications. Part i) shows that if the participation constraint of the PU does not bind, either because the cost of change is low or the outside option is unattractive, the MU will offer contracts that balance the internal competition. However, the MU only offers a monetary bonus to the RU and relies on the non-monetary cost of change F to motivate the PU. The reason is, as discussed above, that the PU's effort comes at a higher cost than the value it creates to the firm. Offering a monetary bonus to both units in order to obtain higher efforts is therefore not profitable.

Part ii) of Proposition 5 concerns the case where a fully balanced conflict would require a fixed wage to the PU to ensure that \mathcal{C}_P is accepted.¹⁴ Here, the MU uses B to balance the conflict, but only up to the point where the voluntary participation constraint of the PU binds. Increasing B beyond this threshold would make the RU stronger, balance the conflict further, and result in higher efforts. However, the extra cost in terms of higher wages outweighs the expected benefit, and the MU prefers to maintain the competition unbalanced.

5.2.3 Discussion

We have followed an incomplete contract approach by assuming that the characteristics of a technology can be observed ex-post, in particular its value, but cannot be included in a contract

¹⁴Notice that the payoff of the PU is decreasing in the strength of the RU.

ex-ante. In recent years, there has been a heated debate in economics concerning the foundations for this type of contractual incompleteness. In an influential paper, Maskin and Tirole (1999) show that as long as the players can forecast the payoffs from their actions ex-ante and can observe the characteristics of the technology ex-post, they can design mechanisms (so-called "message games") that allow them to obtain the same outcome as they would have obtained had it been possible to contract directly on the characteristics of the technology. The rejoinder from proponents of the incomplete contract approach has been to show that such mechanisms do not do better than no ex-ante contract if technologies are sufficiently complex to describe and the parties cannot refrain from renegotiating undesirable outcomes (Hart and Moore 1999; Segal 1999).

We have nothing to add to this ongoing debate, and we acknowledge that our work is exposed to the Maskin-Tirole type of criticism. Nevertheless, we would like to note that the assumption that the values of the technologies are perfectly observed ex-post is stronger than needed. We have explored an alternative setup where the MU only observes which technology is the most valuable one, but it does not observe the absolute values. This assumption captures the idea that one of the advantages of a contest is that it requires only ordinal comparisons among alternatives. Adopting this alternative assumption comes at a cost in terms of the complexity of the analysis but does not change our results qualitatively.

At this stage, one can wonder how the insights from the skunk works model of innovation change if we allow for monetary incentives to the RU. The short answer is not so much. One needs to distinguish between two cases: whether the monetary reward can or cannot be made contingent upon the trajectory chosen (radical vs. incremental).

In the case of contingent rewards, the MU will only pay a bonus if the radical trajectory is chosen.¹⁵ It can choose a reward large enough such that the RU prefers the radical trajectory despite the strong competition from the PU. However, this might result in a very high wage bill and the MU might still find the skunk works model of innovation an attractive solution. In fact, one can show that under the skunk works model the RU chooses the radical trajectory for a smaller bonus paid contingent on a radical technology being adopted.

When the rewards cannot be made contingent upon the trajectory chosen - which we believe is the most plausible situation - the MU cannot use monetary incentives to induce the choice of the radical trajectory. The analysis of the previous section applies almost unchanged. The only difference is that now the MU can use a monetary reward to make the competition more balanced and thus increase its expected profits.

A last issue that deserves some discussion concerns the productivity of the PU. It has been assumed that the defensive effort produces no value added, which drives the result that no

¹⁵We focus on the interesting case in which the firm prefers the radical trajectory but the RU chooses the incremental trajectory to avoid costly competition from the PU.

monetary bonus is offered to the PU. Of course, if the defensive effort were sufficiently productive, it would be optimal to offer a monetary bonus to the PU as well. In this case, the optimal contracts balance the internal competition, include a monetary bonus to both units, and induce one of the units to exert the maximal effort. Since little additional insights are added we have preferred to leave this analysis out of the paper.

6 Discussion and Conclusions

When a firm innovates, its organization, or parts of it, need to undergo some changes to adapt to the new course of actions. This process is likely to entail costs, and often the introduction of an innovation faces some internal resistance. In this paper we have analyzed a case in which an innovation imposes re-adjustment costs upon a production department that, in response to this threat, tries to resist change by making the current technology more valuable to the firm. This situation is modelled as an internal competition between an R&D department that investigates and proposes new solutions, and a production department that defends the status-quo. We have shown that stronger resistance to change due to larger re-adjustment costs is not necessarily a problem for a firm. To the contrary, firms with a capable R&D department can leverage such resistance to change to foster more valuable innovations as well as larger improvements of the existing technology.

A key insight from our analysis is what we have labeled as the "principle of balanced competition". In fact, we have shown that, other things equal, firms that successfully maintain a balance between the two departments outperform firms where one department largely dominates the other. Balanced internal competition stimulates efforts both from the production department to improve and perfect the actual technology and from the R&D department to investigate and propose even better solutions.

The principle of balanced competition is similar in spirit to the recommendation by organization scholars that the successful firm should pursue a balance between exploration of new alternatives and the exploitation of current capabilities (Levinthal and March 1993; Rivkin and Siggelkow 2003). In our model, while the production department is devoted to improve and perfect the actual technology, the R&D department is in charge of identifying and exploring new opportunities. We contribute to this literature by offering a different, incentive-based view of the tension between exploitative and explorative activities. The traditional argument is that by investing too much in one activity the firm develops routines and accumulates learning that are idiosyncratic to this activity, and that reduces its ability to perform the other activity. Instead, we argue here that the firm should maintain a balance between these activities because they compete for scarce resources, and such competition generates the highest payoff to the firm when it is equal footed.

This principle has important implications for practitioners too. In fact, there are several different ways through which the management can influence the relative strength of the two departments. One such possibility is through the choice of the talent of the people hired for the two departments. For instance, a firm that faces very strong resistance to change should hire more able researchers to leverage the internal competition further. This emphasizes the point made above that strong inertial forces are not necessarily a disadvantage for a firm, but can - if properly managed - spur both innovation and performance. Again, the general principle is that the firm chooses a labor force composition that balances the strength of the two departments. This result is of a similar flavor to early work by Lazear and Rosen (1981) who suggested that workers in a promotion contest should be matched in groups of similar ability.¹⁶ An alternative way to balance the internal competition is to handicap the stronger department by implementing a biased "innovation policy". For instance, the management of a firm with strong resistance to change should implement the technology proposed by the R&D department even if it is not quite as good as the improved existing technology. One problem that the management faces when implementing such a policy is that it requires commitment because the less profitable technology sometimes has to be chosen. Rotemberg and Saloner (2000) propose to hire managers with an intrinsic preference for certain kinds of projects as a solution to the commitment problem. For example, a "visionary manager" with a preference for new technologies might help to strike a better balance between a strong production department and a weak R&D department.

Our model deliberately emphasizes the benefits of internal competition and thus the importance of managing such competition in the most efficient way. However, we do not deny that competition between the departments might give rise to costs as well. These costs can take the form of lack of collaboration, failure to establish a corporate culture, influence activities, etc. In the second part of the paper, we address this issue by looking at the potential distortion that the threat of internal competition might generate in the choice of the research trajectory. The problem arises when the R&D department chooses an incremental trajectory instead of a more radical trajectory to avoid a costly competition with the production department. We show that the firm can restore the incentives to choose a radical trajectory by implementing the so-called "skunk works model" of innovation, which consists of isolating the R&D department from the rest of the firm. This provides, to the best of our knowledge, the first formal analysis of the skunk works model; an innovation model that has been widely discussed in the business press and extensively applied by firms like IBM, Siemens, Philips and Intel, among others.

Stretching a bit the boundaries of our model, one could argue that re-adjustment costs in the case of radical innovations are especially important for large established firms. Thus, our paper fits well within the organization literature that has analyzed extensively the problems that

¹⁶By contrast, Rotemberg and Saloner (1995) argue that when the competition between the two departments results in resources being wasted on influence activities, the firm can potentially mitigate such a negative effect by making the competition very unbalanced, i.e. by hiring talented employees only in one department.

large established incumbents have in developing and adopting radical innovations that require completely new sets of routines and capabilities (Henderson and Clark 1990; Henderson 1993; Ghemawat 1991). We contribute to this literature by emphasizing that even if established firms might be endowed with the routines and capabilities to cope with radical innovations, the threat of costly internal competition might prevent the R&D department from exploring more radical research trajectories.

Two important considerations for managers have emerged from our analysis of the skunk works model. First, the key element of the skunk works model is that the information flows between the R&D department and the rest of the organization are eliminated. This finding implies that secrecy and autonomy are very important for this organizational solution to function properly. If it is possible to infer the type of project on which the R&D department is working, e.g., from financial accounts or internal memos, our analysis suggests that the advantage of the skunk works model of innovation is lost. Second, our paper shows that in order to induce the R&D department to choose the radical trajectory, the expected reward it must obtain should be sufficiently large. This implies that researchers who are part of a skunk works model must have a “taste” for radical innovations, that is, they should enjoy working in an experimental, risky, exciting environment where major breakthroughs could emerge, but where lots of uncertainties are still unsolved. Thus, the selection of the researchers who should belong to the skunk works model is a critical task for the management of the firm and its human resources department.

As a final consideration, our approach has stressed the importance of generating incentives through internal competition when contracting possibilities are either limited or too costly. The complexities and uncertainties of the innovation process make an incomplete contract approach quite reasonable within our context. However, we believe that, except in cases where contracting possibilities are extremely good, the insights of our analysis are still valid and relevant when more contractual solutions are available. The role of monetary rewards is then to top up non-monetary incentives and to balance the competition between the departments.

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7 Proof of Lemmata and Propositions

7.1 Proof of Lemma 2

The maximal amount that the RU and the PU would be willing to invest into the contest are pB and pF , respectively. Following the argument outlined in the proof of Lemma 1, it can be shown that there does not exist an equilibrium in mixed strategies where the two units randomize among a finite number of effort levels. Consider instead an equilibrium where the two units randomize among an infinite number of effort levels. In particular, the PU randomizes among all $e_P \in [0, pF]$ according to the distribution function $G(\cdot)$, and the RU randomizes among all $e_R \in \left[0, \frac{pF}{\gamma}\right]$ according to the distribution function $H(\cdot)$. Assuming that the RU does not put probability mass on any effort level, which is satisfied in equilibrium, the expected utility of the PU can be written as:

$$U_P = p(1 - H(e_P/\gamma))(w - e_P - F) + (1 - p(1 - H(e_P/\gamma)))(w - e_P) \Leftrightarrow \\ H(e_R) = \frac{U_P - w + pF}{pF} + \frac{\gamma e_R}{pF}.$$

Turning to the RU, we have:

$$U_R = pG(\gamma e_R)(B - e_R) + (1 - pG(\gamma e_R))(-e_R) \Leftrightarrow \\ G(e_P) = \frac{U_R}{pB} + \frac{e_P}{p\gamma B}.$$

Using $G(pF) = 1$ and $H(pF/\gamma) = 1$, it follows that:

$$H(e_R) = \frac{\gamma e_R}{pF} \text{ for all } e_R \in \left[0, \frac{pF}{\gamma}\right] \text{ and } U_P = w - pF, \\ G(e_P) = 1 - \frac{F}{\gamma B} + \frac{e_P}{p\gamma B} \text{ for all } e_P \in [0, pF] \text{ and } U_R = p(B - \frac{F}{\gamma}).$$

Finally, the expected profits of the firm can be written as:

$$E\Pi = \int_0^{\frac{pF}{\gamma}} \{G(\gamma e_R) [(p\gamma e_R + (1 - p)E(e_P|e_P < \gamma e_R)) + (1 - G(\gamma e_R))E(e_P|e_P > \gamma e_R)] h(e_R) de_R,$$

where $E(e_P|e_P < \gamma e_R) = \frac{1}{G(\gamma e_R)} \int_0^{\gamma e_R} \frac{e_P}{p\gamma B} de_P$, and $h(e_R) = \frac{\gamma}{pF}$. Simplifying the expression, we obtain the expected profits reported in the Lemma.

7.2 Proof of Remark 1

The expected efforts are obtained using the distribution functions reported in Lemma 2 and 3 and integrating over the relevant intervals.

7.3 Proof of Remark 2

The comparative statics follow directly from differentiating the profit expressions in Lemma 2 and 3 and from the expected efforts reported in Remark 1.

7.4 Proof of Lemma 4

The expected profits are calculated using the equilibrium strategies found in the Appendix. The sign of $\partial\pi_1(\alpha)/\partial\alpha$ follows directly from $\partial\pi_1(\alpha)/\partial\alpha = [\partial\pi_1(\alpha)/\partial\pi_0(\alpha)] [\partial\pi_0(\alpha)/\partial\alpha]$ where $\partial\pi_0(\alpha)/\partial\alpha > 0$.

7.5 Proof of Proposition 2

A myopic firm chooses α to solve $\partial\pi_0(\alpha)/\partial\alpha - \partial C(\alpha)/\partial\alpha = 0$ whereas a forwarding-looking firm solves $\partial\pi_0(\alpha)/\partial\alpha + \partial\pi_1(\alpha)/\partial\alpha - \partial C(\alpha)/\partial\alpha = 0$. The proof follows then from the concavity of the profit function in α and the sign of $\partial\pi_1(\alpha)/\partial\alpha$ as reported in Lemma 4.

7.6 Proof of Proposition 3

First notice that Assumption 3 implies that the RU chooses the incremental trajectory under the integrated model of innovation. Consider now the skunk works model. Here, there cannot exist an equilibrium where the RU chooses the incremental trajectory. In such an equilibrium, the PU randomizes according to $G(e_P) = 1 - \frac{F_L}{B} + \frac{e_P}{B}$ for all $e_P \in [0, F_L]$ and $U_R = G(e_R)B - e_R$. The RU has an incentive to deviate to the radical trajectory that results in an expected utility of $pG(\gamma e_R)\rho B - e_R$, which is strictly greater than $G(e_R)B - e_R$ for any given e_R since $\gamma > 1$ (Assumption 1) and $p\rho > 1$.

Consider instead an equilibrium where the RU chooses the radical trajectory. From Lemma 3 we know that when $F_R > \gamma\rho B$ the PU randomizes in equilibrium according to $G(e_P) = \frac{e_P}{p\gamma\rho B}$ for all $e_P \in [0, p\gamma\rho B]$ and $U_R = 0$. Suppose that the RU would deviate to the incremental trajectory. This would produce an expected utility equal to:

$$G(\gamma e_R)(B - e_R) + (1 - G(\gamma e_R))(-e_R) = e_R \left(\frac{1}{p\gamma\rho} - 1 \right),$$

which is non-positive since $\gamma > 1$ and $p\rho > 1$. Therefore, the RU has no incentive to deviate. Similarly, when $F_R < \gamma\rho B$ the PU randomizes according to $G(e_P) = 1 - \frac{F_R}{\gamma\rho B} + \frac{e_P}{p\gamma\rho B}$ for all $e_P \in [0, p\gamma\rho B]$ and $U_R = p(\rho B - \frac{F_R}{\gamma})$. Suppose that the RU would deviate to the incremental trajectory. This would produce an expected utility equal to $B - \frac{F_R}{\gamma\rho} + \frac{e_R}{p\gamma\rho} - e_R$. Since $p\rho\gamma > 1$, the optimal effort when deviating to the incremental trajectory would therefore be $e_R = 0$. This would result in an expected utility of $B - \frac{F_R}{\rho\gamma}$. It is easy to see that such deviation is not profitable when $p\rho > 1$. Hence, for $p\rho > 1$ only the radical trajectory can be sustained as an equilibrium outcome of the game.

7.7 Proof of Proposition 4

There are two kinds of solutions to the MU's problem depending on $V_R > V_P$ or $V_P \geq V_R$. Consider the MU's program for the candidate solution where $V_R > V_P \geq 0$. The two contracts

\mathcal{C}_P and \mathcal{C}_R have to satisfy two constraints: a voluntary participation constraint (VPC) and an incentive compatibility constraint (ICC). There is a one-to-one relation between the effort that the PU exerts and the value of the technology. The optimal way for the MU to achieve the desired effort level e_P^* is thus to pay a wage $W > 0$ if $V_P = e_P^*$ and zero otherwise. The incentive constraint (ICC_{PU}) in program (1) below assumes this type of wage scheme. The constraint ensures that the PU's payoff from choosing e_P^* is no less than the payoff from choosing the best alternative, $e_P = 0$. The voluntary participation constraint (VPC_{PU}) guarantees to the PU a payoff greater than or equal to the value of the outside option when the effort e_P^* is exerted. Turning to the contract \mathcal{C}_R , the RU is paid a wage B for an innovation of value $V_R = \gamma e_R^*$. Innovations of a value different from γe_R^* and no innovation result in a wage of zero and of B_\emptyset , respectively. The incentive constraint is slightly different for the RU. Since the optimal contract rewards only innovations of value γe_R^* , the optimal deviation is to choose $e_R = 0$ and report that no innovation was made. The two constraints (ICC_{RU}) and (VPC_{RU}) ensure that deviating from e_R^* is not profitable and that the expected payoff from choosing e_R^* is at least equal to the outside option. Finally, adding the wealth constraints and the domains of V_P and V_R , we arrive at the following program:

$$Max_{(V_P, V_R, W_P, B_R, B_\emptyset)} \{pV_R - pB - (1-p)B_\emptyset + (1-p)V_P - W\} \quad (1)$$

st.

$$\begin{aligned} W - V_P - pF &\geq -K & (\text{VPC}_{PU}) \\ W - V_P - pF &\geq -pF & (\text{ICC}_{PU}) \\ pB + (1-p)B_\emptyset - V_R/\gamma &\geq -K & (\text{VPC}_{RU}) \\ pB + (1-p)B_\emptyset - V_R/\gamma &\geq B_\emptyset & (\text{ICC}_{RU}) \\ W, B, B_\emptyset &\geq 0 \\ V_P &\in [0, \bar{e}_P] \\ V_R &\in [0, \gamma \bar{e}_R] \end{aligned}$$

The contracts reported in Proposition 4 solve this program.

Consider instead the MU's program for the candidate solution where $V_P \geq V_R$, program (2). Here, it is optimal to set $V_R = 0$ because the innovation of the RU is never implemented. That is, $\mathcal{C}_R : B(V_R) = B(\emptyset) = 0$ for all V_R . In equilibrium the creative effort is thus zero, $e_R^* = 0$, and the technology is never changed. The MU solves the following problem:

$$Max_W \{V_P - W\} \quad (2)$$

st.

$$W - V_P \geq -K \quad (\text{VPC}_{PU})$$

$$W - V_P \geq 0 \quad (\text{ICC}_{PU})$$

Since the defensive effort does not create value-added, an optimal contract is $\mathcal{C}_P : W(V_P) = 0$ for all $V_P = 0$. These contracts result in expected profits equal to zero.

Finally, comparing the profits for the two candidate solutions, it can be shown that the contracts derived for the case $V_R > V_P \geq 0$ are optimal.

7.8 Proof of Lemma 5

Suppose that the PU dominates and that $B > W$. Then, the PU randomizes according to $G(e_P) = \frac{B-W+e_P}{\gamma p B}$ for all $e_P \in [0, (\gamma p - 1)B + W]$ and the RU randomizes according to $H(e_R) = 1 - \frac{\gamma B}{F+W} + \frac{\gamma e_R}{p(F+W)}$ for all $e_R \in \{0\} \cup [(B-W)/\gamma, pB]$.

Suppose instead that the PU dominates but that $B \leq W$. Then, the PU randomizes according to $G(e_P) = \frac{B-W+e_P}{\gamma p B}$ for all $e_P \in [W - B, (\gamma p - 1)B + W]$ and the RU randomizes according to $H(e_R) = 1 - \frac{\gamma B}{F+W} + \frac{\gamma e_R}{p(F+W)}$ for all $e_R \in [0, pB]$.

The expected profits are calculated as in the proof of Lemma 2, the only difference being that the bonuses are monetary and therefore represent a cost for the firm.

7.9 Proof of Proposition 5

We consider two cases, $K \geq pF$ and $K < pF$.

Case I: $K \geq pF$.

The PU can always ensure a payoff of $-pF$ by choosing $e_P = 0$. Hence, the participation constraint does not bind and $\widetilde{W} = 0$. The optimal bonuses are such that $B \geq W$ since $\partial \Pi(B, W, 0)/\partial W \leq 0$ for $W > B$. Hence, $B \in [W, (p(F+W) - W)/(p\gamma - 1)]$ where the upper bound on B guarantees that the PU dominates. Notice that this implies that $W \in [0, F/(\gamma - 1)]$.

Since $\partial^2 \Pi(B, W, 0)/\partial B^2 > 0$, there are two sets of solutions depending on $B = W$ or $B = (p(F+W) - W)/(p\gamma - 1)$. Consider first the candidate solutions for which $B = W$. Since $\partial^2 \Pi(W, W, 0)/\partial W^2 > 0$, the candidate solutions are $B = W = 0$ and $B = W = F/(\gamma - 1)$.

Consider instead the candidate solutions for which $B = (p(F+W) - W)/(p\gamma - 1)$. Here, $\partial^2 \Pi((p(F+W) - W)/(p\gamma - 1), W, 0)/\partial W^2 > 0$. This results in an additional candidate solution, $B = pF/(p\gamma - 1)$ and $W = 0$, plus the previous candidate solution $B = W = F/(\gamma - 1)$.

Finally, comparing the profits of the three candidate solutions, the result reported in the proposition is obtained.

Case II: $K < pF$.

From (Program of the MU) follows that there are two cases to consider. The (VPC_{PU}) binds for $B > K/(p\gamma - 1)$ whereas it does not bind for $B \leq K/(p\gamma - 1)$. Only the proof for the case

$K/(p\gamma - 1) < F/(\gamma - 1)$ is included, but the proof for the other case is similar. Details are available upon request.

As in Case I, it has to hold that $B \in [W, (p(F + W) - W)/(p\gamma - 1)]$ and $W \in [0, F/(\gamma - 1)]$. Furthermore, because $\partial^2 \Pi(B, W, 0)/\partial B^2 > 0$ both for $B > K/(p\gamma - 1)$ and $B \leq K/(p\gamma - 1)$, the optimal bonus B is a corner solution.

Consider first $B \in [W, K/(p\gamma - 1)]$ where $\widetilde{W} = 0$. There are two sets of solutions depending on $B = W$ or $B = \frac{K}{p\gamma - 1}$ (as $\frac{K}{p\gamma - 1} < \frac{p(F+W)-W}{p\gamma - 1}$ in the case considered). Similar to Case I, the candidate solutions for $B = W$ are: i) $B = W = 0$ and ii) $B = W = K/(p\gamma - 1)$. For $B = \frac{K}{p\gamma - 1}$, it can be shown that $\partial \Pi(\frac{K}{p\gamma - 1}, W, 0)/\partial B < 0$. Hence, the candidate solution is: iii) $B = \frac{K}{p\gamma - 1}$ and $W = 0$. Comparing the three candidate solutions, $\partial \Pi(\frac{K}{p\gamma - 1}, W, 0)/\partial B < 0$ implies that candidate solution iii) dominates candidate solution ii). Furthermore, candidate solution iii) dominates candidate solution i) because $\Pi(0, 0, 0) < \Pi(\frac{K}{p\gamma - 1}, 0, 0)$. Hence, the optimal bonuses for $B \in [W, K/(p\gamma - 1)]$ are $B = K/(p\gamma - 1)$ and $W = 0$.

Consider instead $B \in [K/(p\gamma - 1), (p(F + W) - W)/(p\gamma - 1)]$ where $\widetilde{W} = B(\gamma p - 1) - K$. For $B = K/(p\gamma - 1)$, the relevant candidate solution is again: i) $B = K/(p\gamma - 1)$ and $W = 0$. For $B = \frac{p(F+W)-W}{p\gamma - 1}$, $\partial^2 \Pi((p(F + W) - W)/(p\gamma - 1), W, 0)/\partial W^2 > 0$ implies that the candidate solutions are: ii) $B = W = F/(\gamma - 1) > K/(p\gamma - 1)$ and iii) $B = \frac{pF}{p\gamma - 1}$ and $W = 0$. Here, as $\Pi(K/(p\gamma - 1), 0, 0) > \Pi(K/(p\gamma - 1), K/(p\gamma - 1), 0) > \Pi(F/(\gamma - 1), F/(\gamma - 1), F(\gamma p - 1)/(\gamma - 1) - K)$, candidate solution i) dominates candidate solution ii). Furthermore, as $\partial \Pi(B, 0, B(\gamma p - 1) - K)/\partial B < 0$ for $B > K/(p\gamma - 1)$, candidate solution i) dominates candidate solution iii).

Summarizing the two cases, the optimal bonuses are $B = pF/(p\gamma - 1)$ and $W = 0$ for $K < pF$.